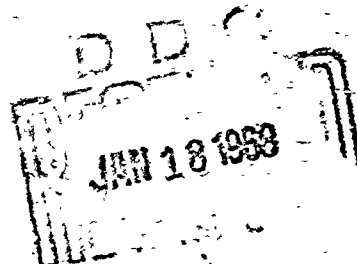# Measurement of Spectral Radiance of the Horizon Sky

December 4, 1967

NAVAL RESEARCH LABORATORY
Washington, D.C.

Measurement of Spectral Radiance of the Horizon Sky

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CONTENTS

i

ABSTRACT

Spectral radiance data were obtained for a rectangular portion of the horizon sky under various weather conditions and at different solar positions. Representative curves were selected from 79 spectral radiance measurements which covered meteorological ranges (at 665 mμ) from 10 to 106 km and solar altitudes from -6 to 74 degrees. The north horizon at noon, with a 30 km or greater meteorological range, typically produced a peak spectral radiance of 5 μw/cm^2-srad-mμ. The maximum spectral radiance value obtained in the study was 38 μw/cm^2-srad-mμ for the south horizon in winter. The reciprocal dispersion varied from 1.8 mμ/mm at 400 mμ to approximately 8 mμ/mm at 1000 mμ. A mixture of fog and haze produced a spectral radiance curve with two maxima.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

MEASUREMENTS OF SPECTRAL RADIANCE
OF THE HORIZON SKY

INTRODUCTION

The spectral radiance of small areas of sky in the infrared region has been studied by Bell, et al. (1), among others. However, very little data have been published on the spectral radiance of the horizon sky in the visible region. Such information is desirable in connection with over-the-horizon scattering studies now being made.

The spectral region of interest extended from the ultraviolet transmission limit of glass (~ 400 mμ) to 1000 mμ. Rectangular portions of the horizon sky were observed at two or three well-spaced bearings, mainly over water. A method of calibration was devised to minimize experimental error, and curves were obtained which show the spectral radiance as a function of wavelength under different conditions, some typical and others atypical. A short study was made of the effects that polarization of the horizon sky would have on the measurements because the monochromator exhibits polarization preference. Correction of the radiance data was unnecessary.

Reports on this work have been presented elsewhere (2,3) but with only a few spectral radiance curves included. It was felt that all the reduced data should be compiled for reference purposes. From a total of 79 measurement runs, 45 were selected for reduction and are presented in this report.

INSTRUMENTATION

A Leiss double monochromator with glass prisms was used to disperse the radiation. The reciprocal dispersion varied from 1.8 mμ/mm at 400 mμ to approximately 8 mμ/mm at 1000 mμ when all three slits were fixed at 0.6 mm for all measurements. A field stop in front of the entrance slit limited the field of view to 75 mrad (4.3 degrees) wide by 25 mrad (1.4 degrees) high. A beam-splitter reflected a portion of the incoming radiation to the monitor, an RCA 6342 (S-11 response) photomultiplier with a red filter.

The wavelength scan was divided into two parts: an RCA 7265 (S-20 response) photomultiplier was used from 380 to 760 mμ, and a Dumont 6911 (S-1 response) photomultiplier was used from 610 to 1000 mμ. The dc output voltage of the detector was amplified and recorded on one channel of a two-channel Sanborn recorder; the other channel was used for the monitor output.

CALIBRATION

The relative spectral response of the monochromator-detector system was measured with a working-standard lamp which had been calibrated against an NBS standard of spectral radiance. The signal, due to the light transmitted by the monochromator, divided by the corresponding relative spectral radiance value for the lamp gave the relative spectral response of the system at a given wavelength.

1

A normalizing absolute radiance measurement was made at one wavelength at the time of each run by viewing with an optical pyrometer the same area of sky observed with the monochromator. The "temperature" thus obtained was converted to radiance at 665 mμ, the effective wavelength of the pyrometer (4).

Three sources of error were possible in the calibration: the standard lamp, the electronics, and the pyrometer. The error in the relative spectral distribution of the lamp is estimated to be $\pm 8\%$, made up of a $\pm 6\%$ error in lamp calibration and a $\pm 2\%$ error due to lamp current setting. The error due to drift or fluctuations in the electronics during the 90 sec required for a wavelength scan is believed to be negligible. A recorder drift of 0.5% was detectable. The radiance values derived from pyrometer readings, most of which were in the neighborhood of 1000°C, had an uncertainty of $\pm 4\%$. At sunrise and sunset, when brightness temperatures were of the order of 800°C, the uncertainty was approximately $\pm 20\%$. Monochromator polarization was measured using an unpolarized tungsten light source and a Glan-Thompson prism. The light emerging from the monochromator was found to have partial horizontal polarization at all wavelengths, the degree of polarization β depending on wavelength. Calculation of the degree of polarization using the expression $\beta = (E_{max} - E_{min})/(E_{max} + E_{min})$ yielded values of 0.34 ± 0.07 from 460 to 1000 mμ.

Since the absolute radiance of the horizon was measured at 665 mμ with the pyrometer, the radiance values at all other wavelengths included the polarization effect at the normalizing wavelength. Therefore, it was necessary to determine only the change as a function of wavelength in the polarization effect of the monochromator relative to the polarization of the sky radiation. The maximum variation observed was -5% of the radiance at a bearing of 100 degrees, a solar azimuth of 200 degrees, and a wavelength of 462 mμ, which was the lowest wavelength of polarization measurement. The average variation was within $\pm 1\%$ and, therefore, no correction for polarization effects was deemed necessary.

FIELD MEASUREMENTS

Measurements were made at three locations, all of which were approximately the same height (100 ft) above sea level. The first measurements, made at NRL, were of the horizon sky over land. Subsequent measurements were made of the horizon sky over water on the western shore of the bay at the Chesapeake Bay Division (CBD) of NRL and at Tilghman Island, Maryland, on the eastern shore.

RESULTS

All spectral radiance observations were made on 16 different days. The range of solar altitudes covered was -6 to 74 degrees, and the azimuth of the sun varied from 58 to 273 degrees. The meteorological range at 665 mμ varied from 10 to 106 km and the relative humidity from 41 to 90 percent. The radiance distributions with wavelength are shown in Figs. 1-5, in order of diurnal solar altitude variation. In general, the spectral radiance distribution varied with solar altitude as expected: the peaks of the curves occurred at wavelengths between 500 and 600 mμ for higher solar altitudes and shifted toward red wavelengths at low altitudes and/or near the sun's azimuth. One major exception to this behavior (Fig. 1b) occurred when fog and haze particles produced a maximum at about 450 mμ equal to or greater than the red maximum. Figure 1c is a curve for the same general direction on a clear day and shows a more typical spectral radiance curve for the sun just below the horizon, giving a peak value at 1000 mμ of 0.65 μw/cm^2-srad-mμ. The points which do not lie on the curve are a result of error in the relative response calibration. This error was greatest when the slope of the response curves was steepest; this situation occurred in the overlap region of the two detectors.
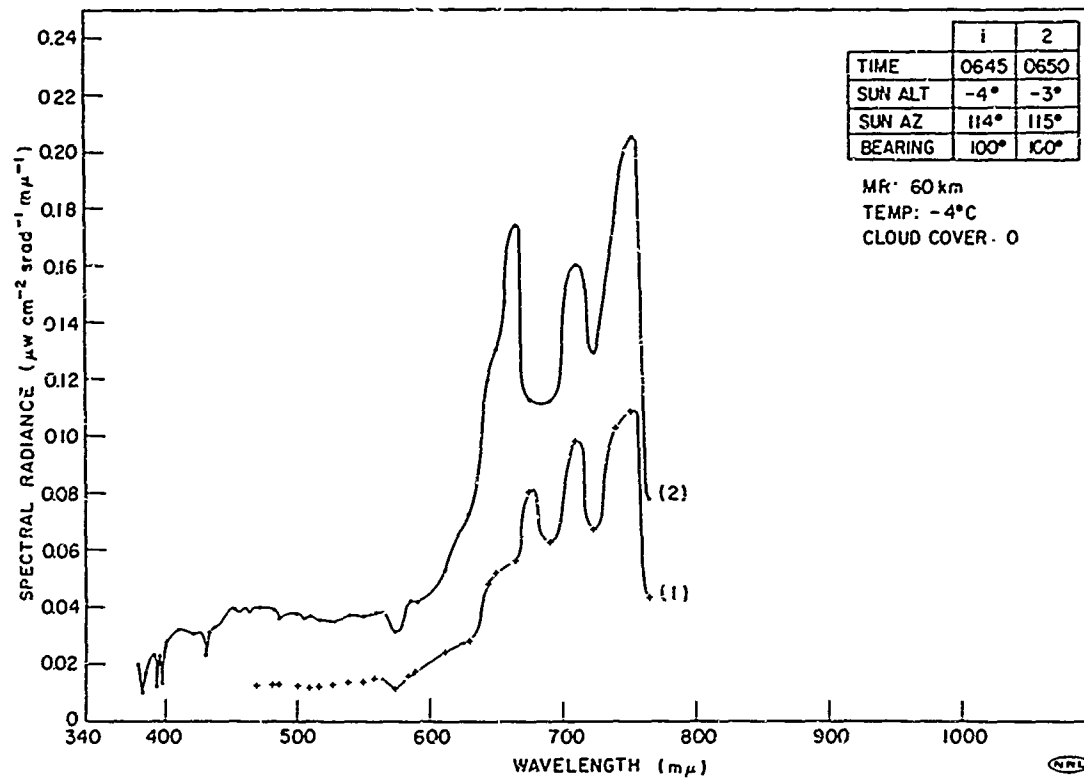
Fig. 1a - Spectral radiance of clear eastern horizon
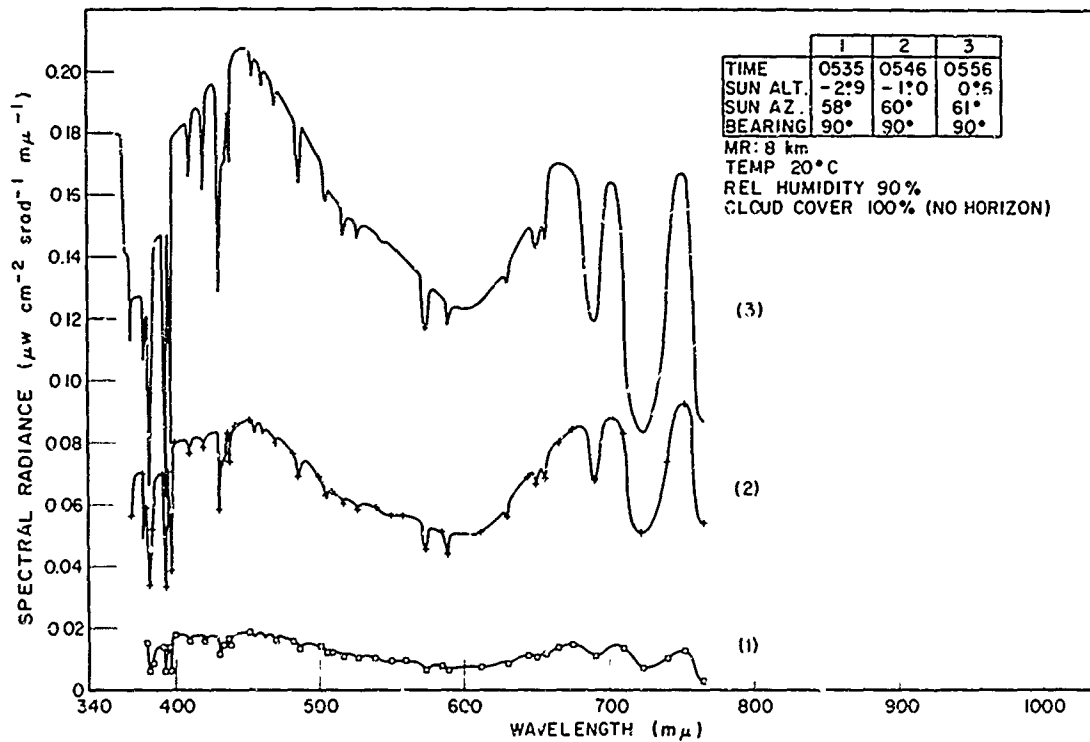over water before sunrise

Fig. 1b - Spectral radiance of fog and haze over water
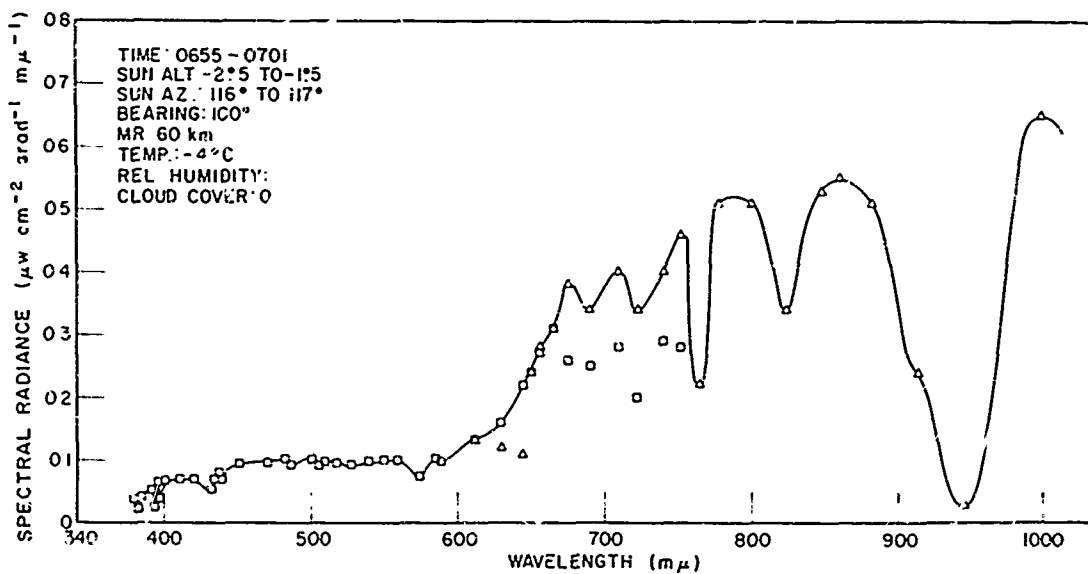near sunrise showing additional maximum in blue region

Fig. 1c - Spectral radiance of clear eastern
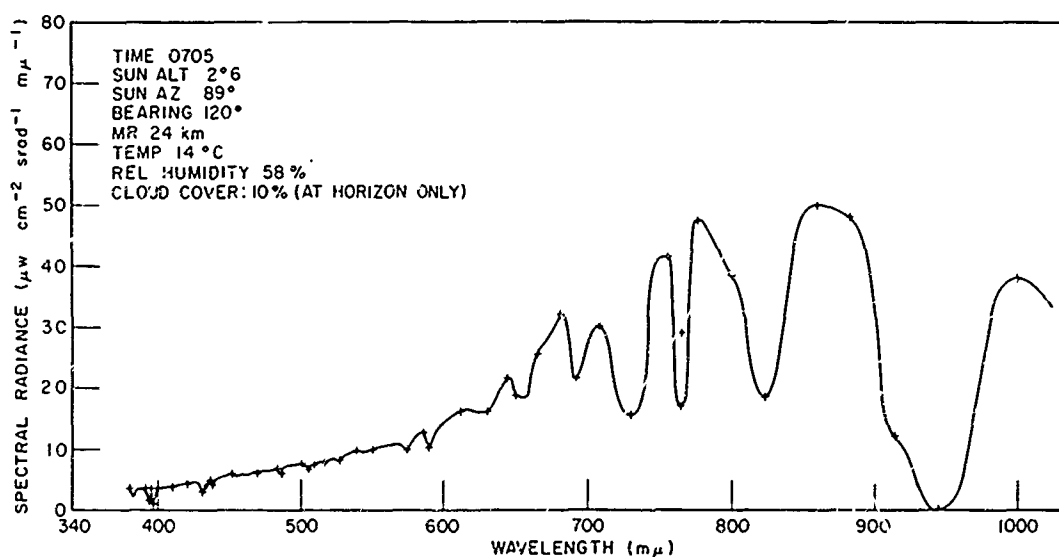horizon over water before sunrise

Fig. 2a - Spectral radiance of southeastern
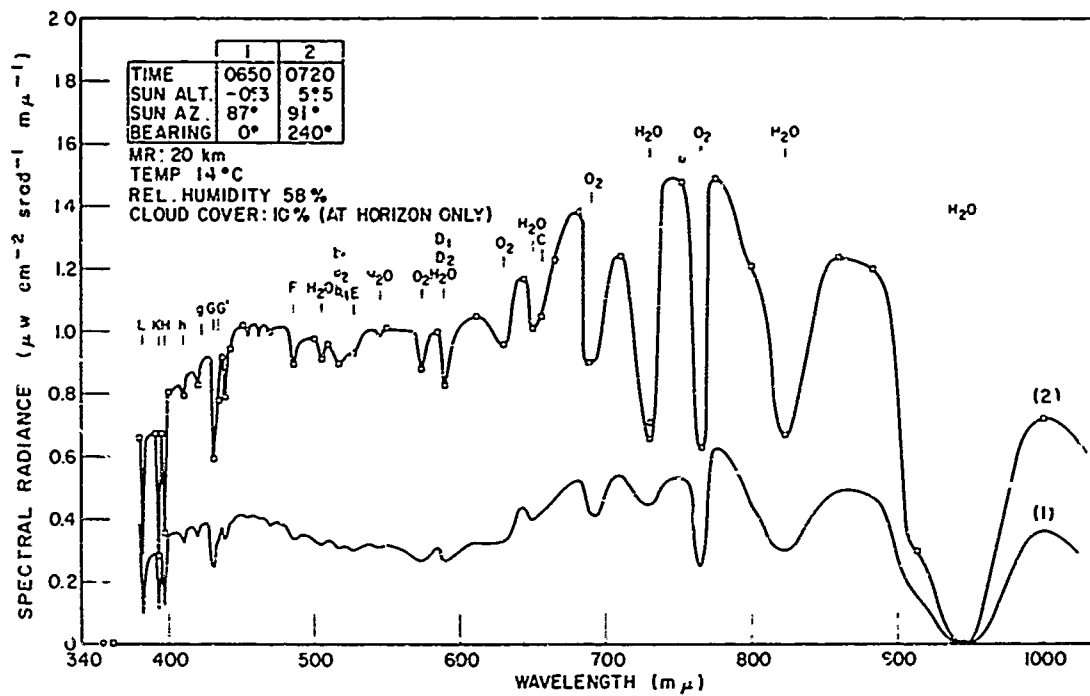horizon over land after sunrise

Fig. 2b - Spectral radiance of northern horizon at sunrise
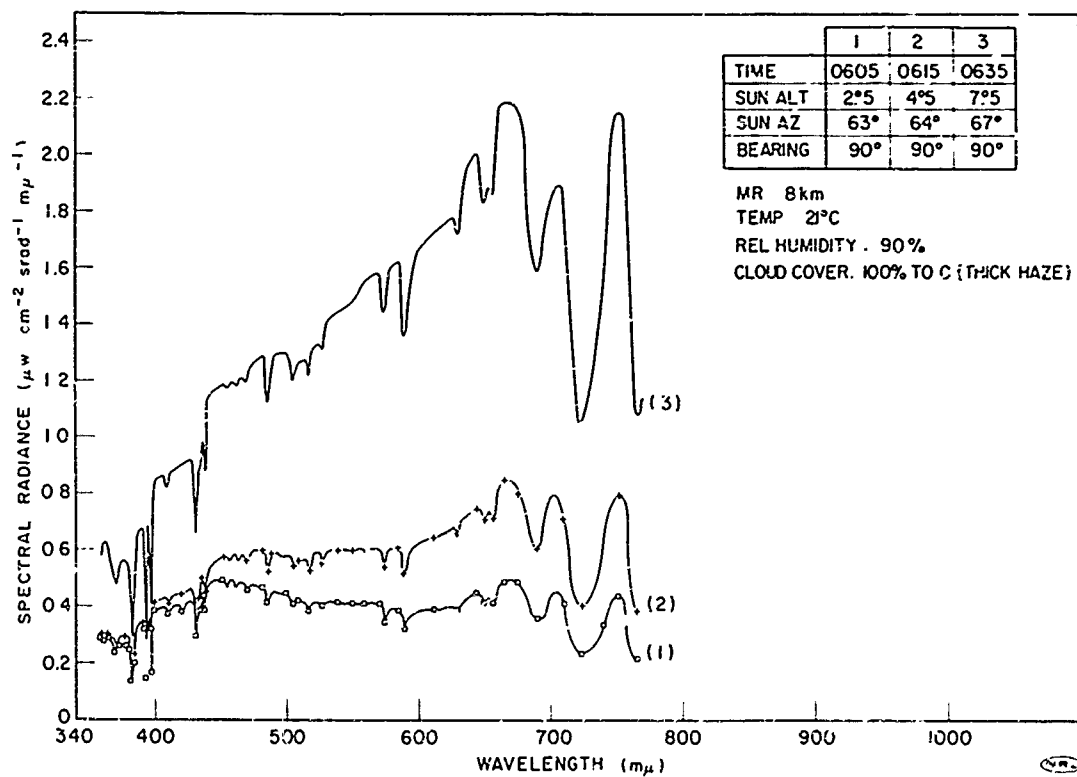and southwestern horizon after sunrise over land

Fig. 2c - Spectral radiance of eastern horizon after
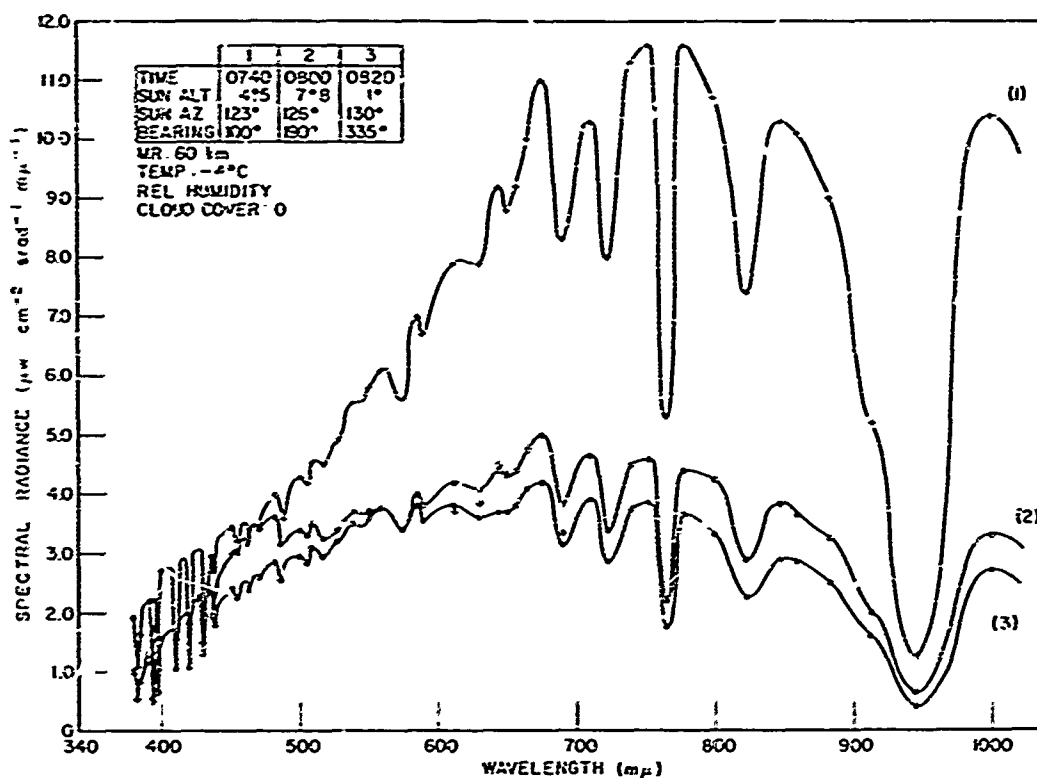sunrise showing amount of change in 30 minutes

Fig. 2d - Spectral radiance of east, south, and north horizons
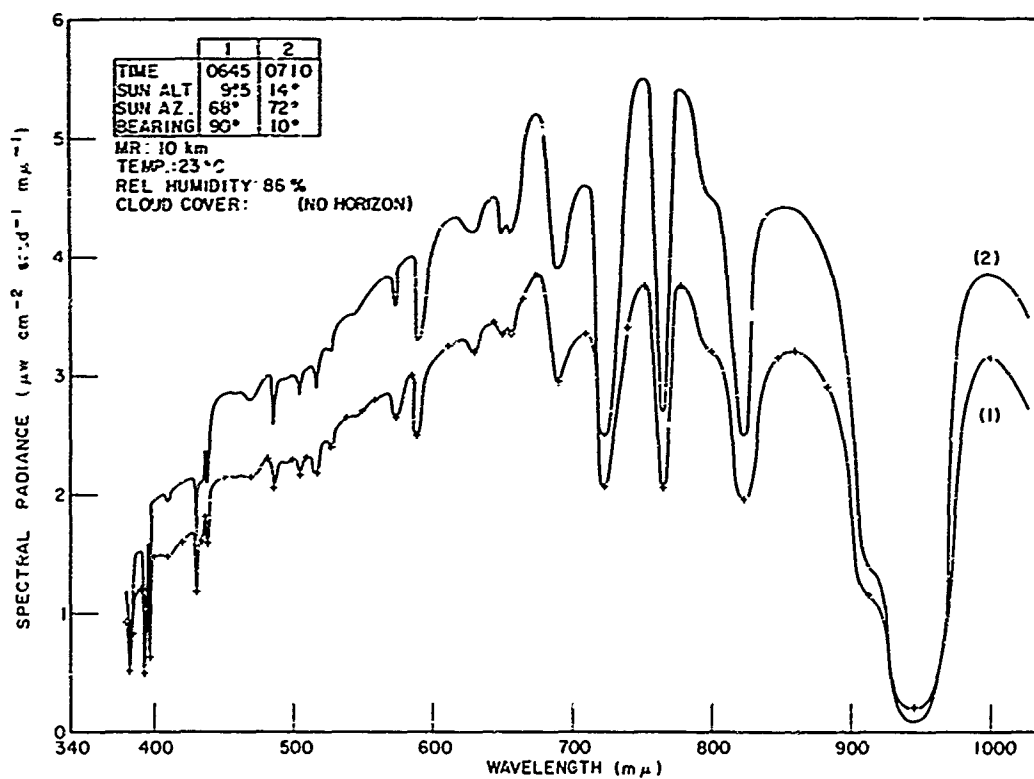over water at low solar altitudes through clear air

Fig. 2e - Spectral radiance toward north and east horizons
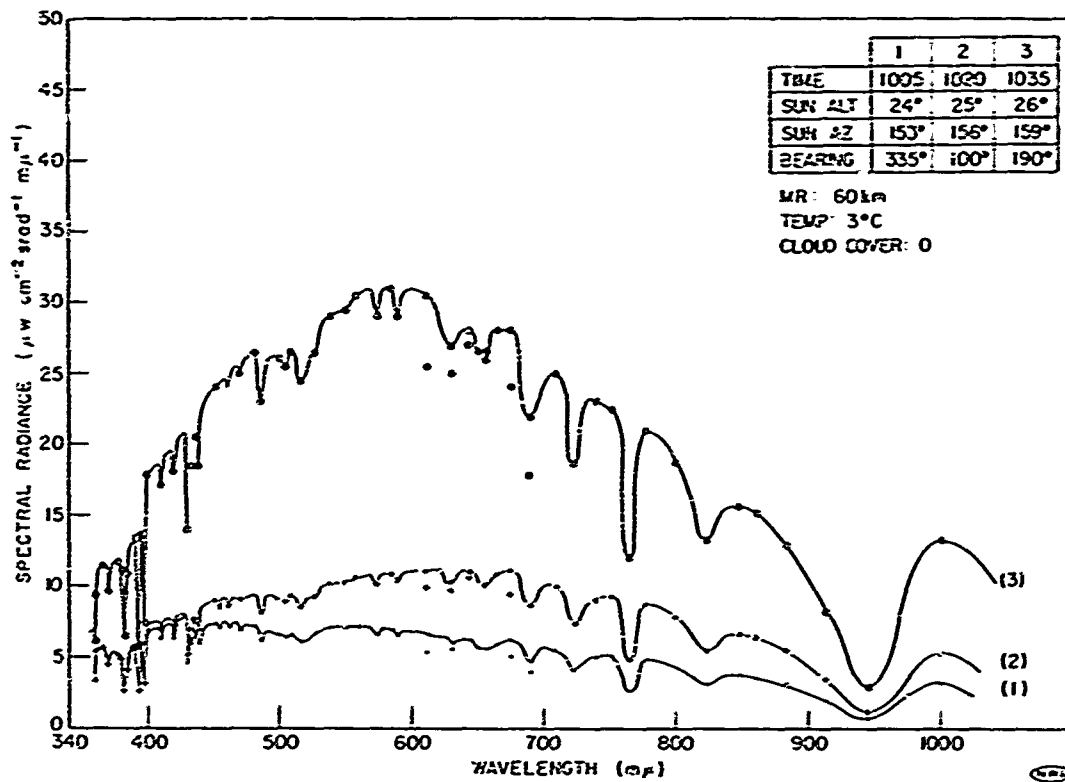over water at low solar altitudes through haze

	1	2	3
TIME	1005	1020	1035
SUN ALT	24°	25°	26°
SUN AZ	153°	156°	159°
BEARING	335°	100°	190°

MR: 60 km
TEMP: 3°C
CLOUD COVER: 0

Fig. 3a - Spectral radiance of horizon in three
directions over water through clear air

	1	2
TIME	0820	0835
SUN ALT	26.5	29.5
SUN AZ	82°	84.5
BEARING	10°	90°

MR: 10 km
TEMP: 24°C
REL HUMIDITY 80%
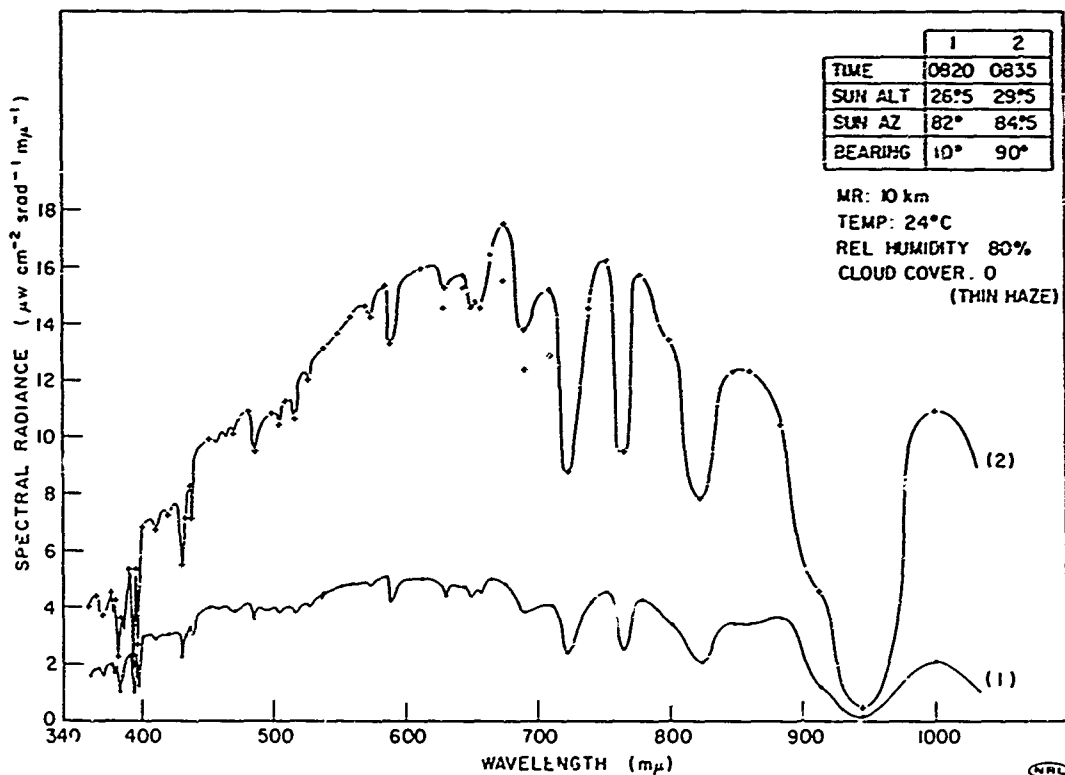CLOUD COVER. 0
(THIN HAZE)

Fig. 3b - Spectral radiance toward north and east
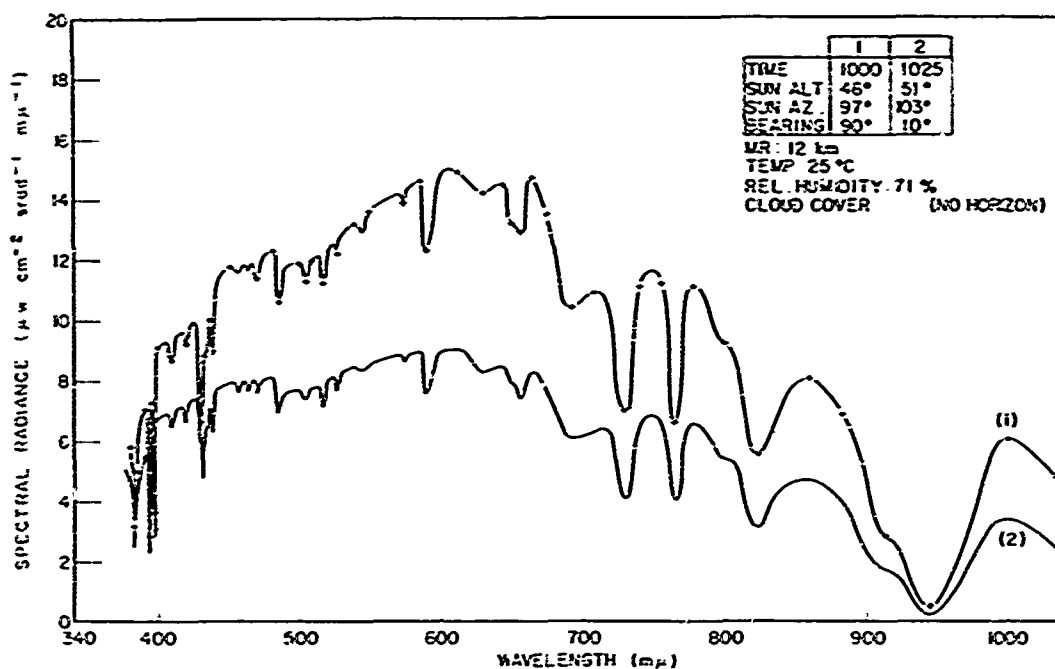horizons over water through haze

Fig. 3c - Spectral radiance to north and east over
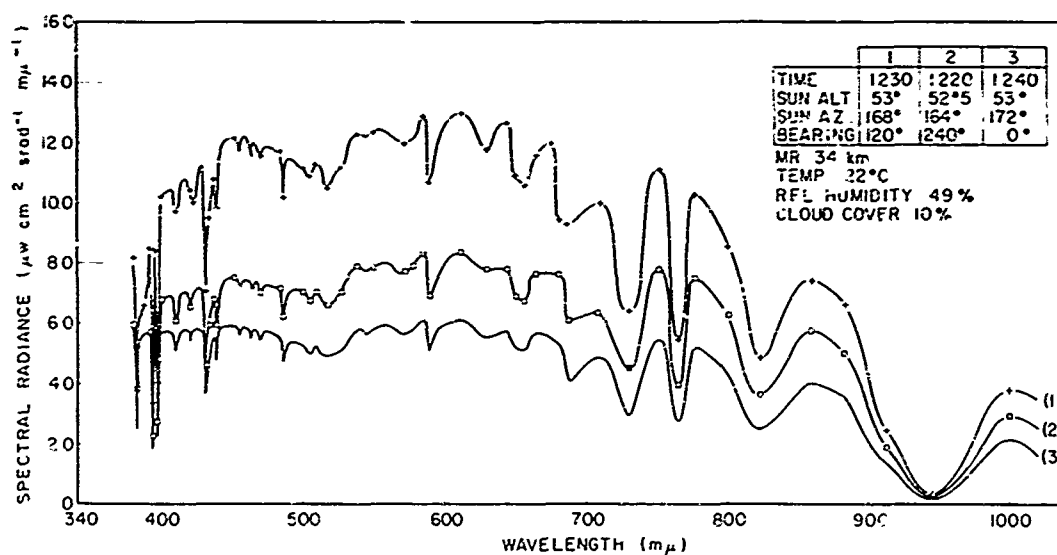water at high solar altitudes through haze

Fig. 3d - Spectral radiance of horizon in three
directions over land at high solar altitudes

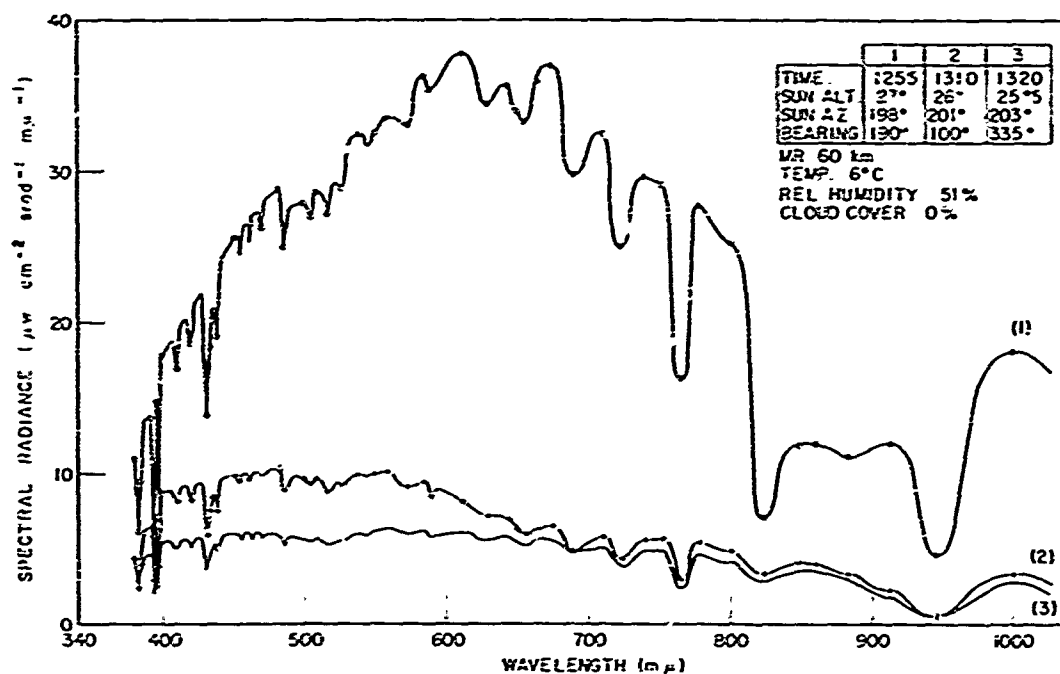Fig. 3e - Spectral radiance of horizon in three directions over
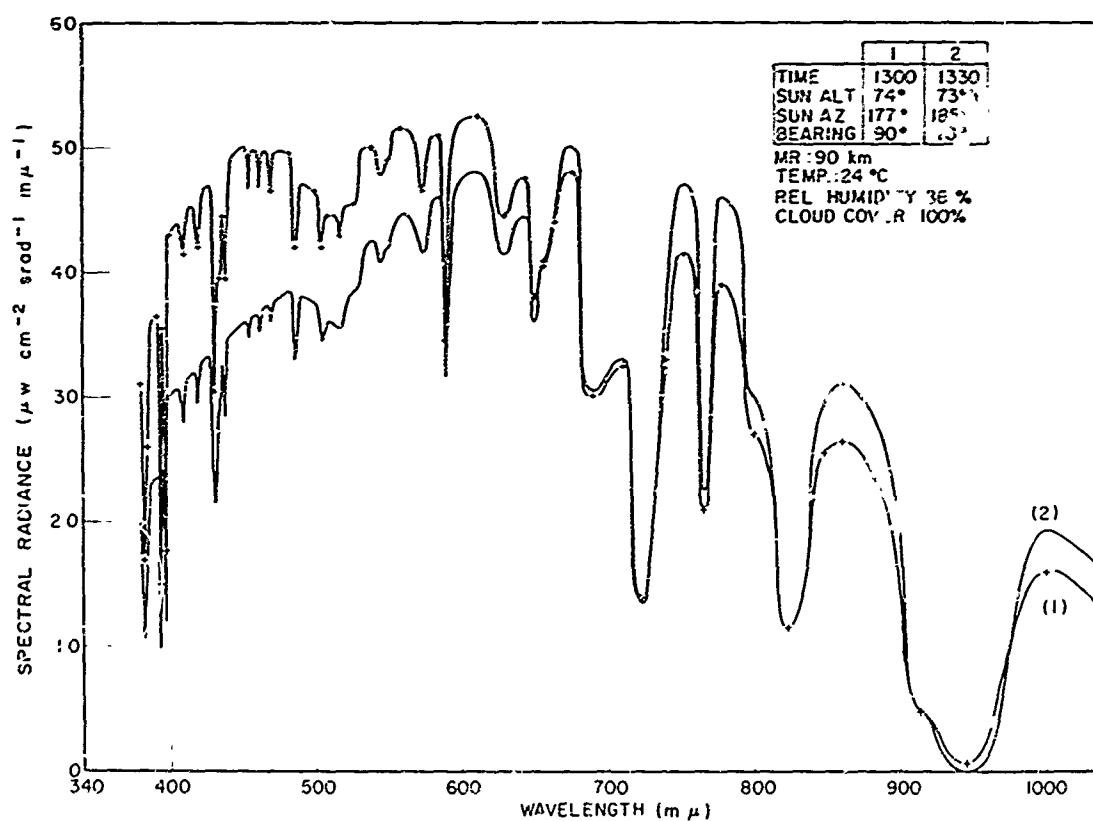water showing high forward scattering in direction of sun

Fig. 3f - Spectral radiance of north and east horizons over
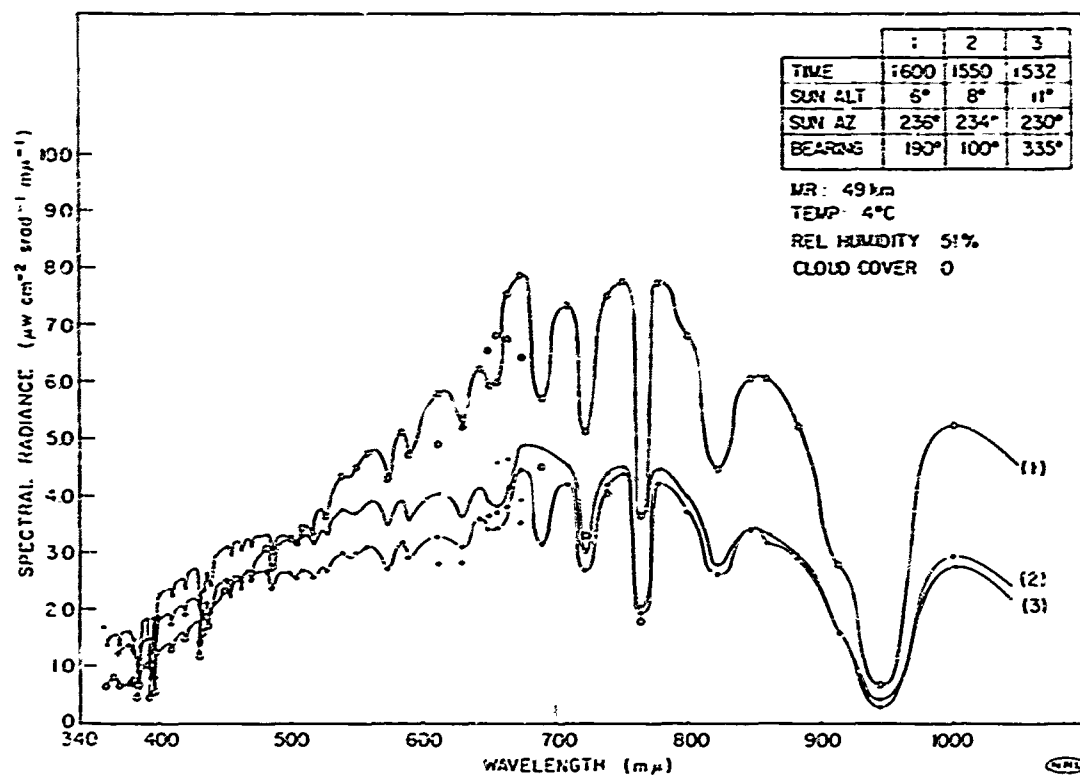water through clear air on overcast day

Fig. 4a – Spectral radiance of horizon in three directions over water in late afternoon
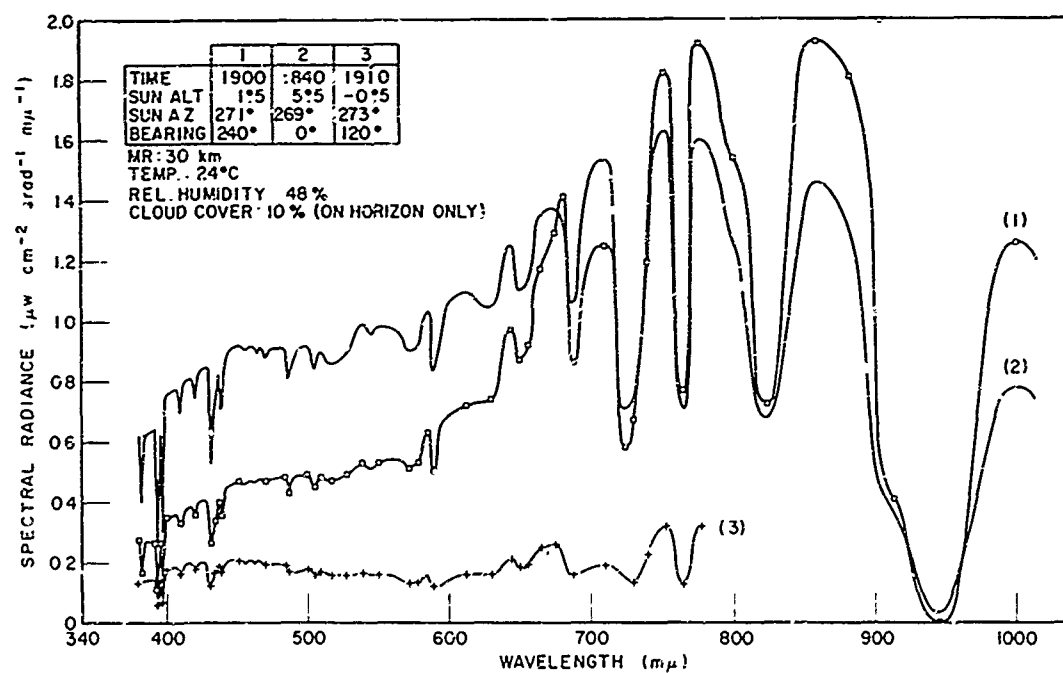
Fig. 4b – Spectral radiance of horizon in three directions over land near sunset

	1	2
TIME	1627	1642
SUN ALT	2°	-0°5
SUN AZ	240°	242°
BEARING	190°	190°

MR .49 km
TEMP 4 °C
REL HUMIDITY 51 %
CLOUD COVER : 0

Fig. 4c - Spectral radiance of south horizon
over water near sunset

	1	2
TIME	1647	1653
SUN ALT	-1°	-2°3
SUN AZ	243°	244°
BEARING	190°	190°

MR 49 km
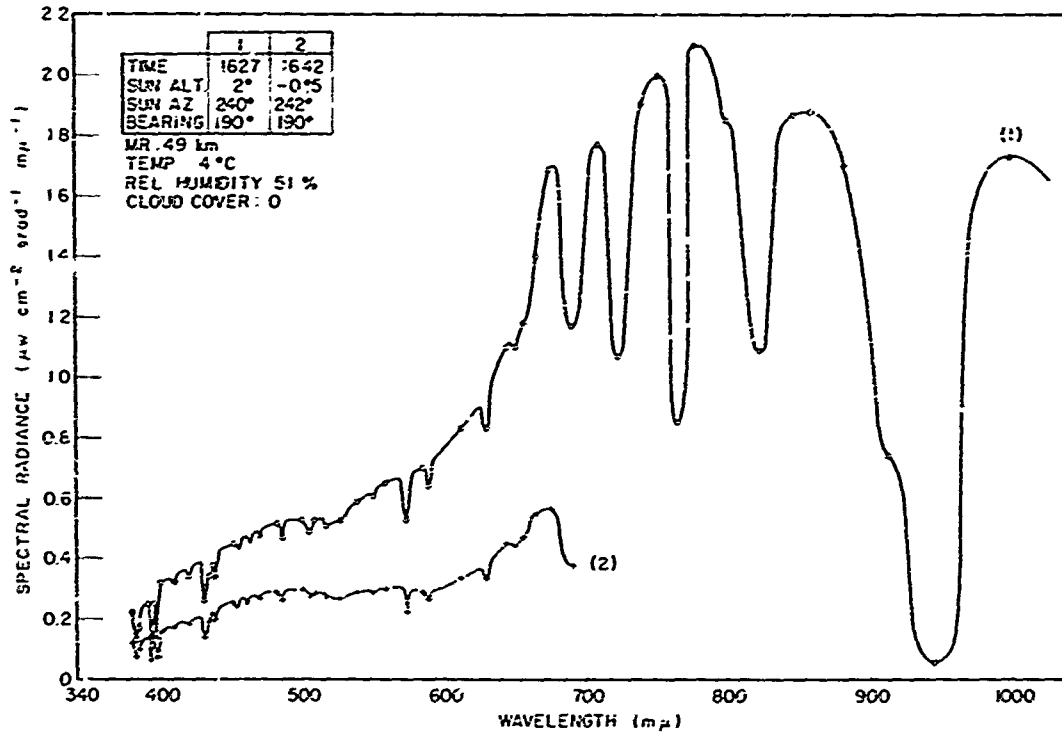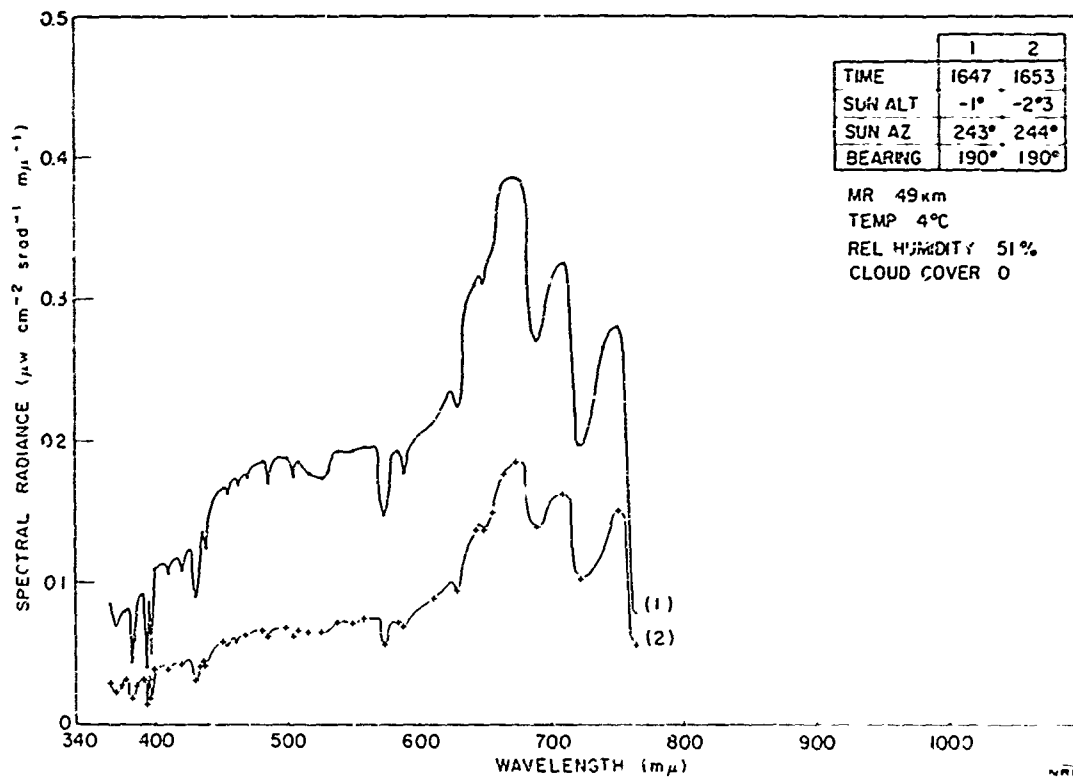TEMP 4°C
REL HUMIDITY 51 %
CLOUD COVER 0

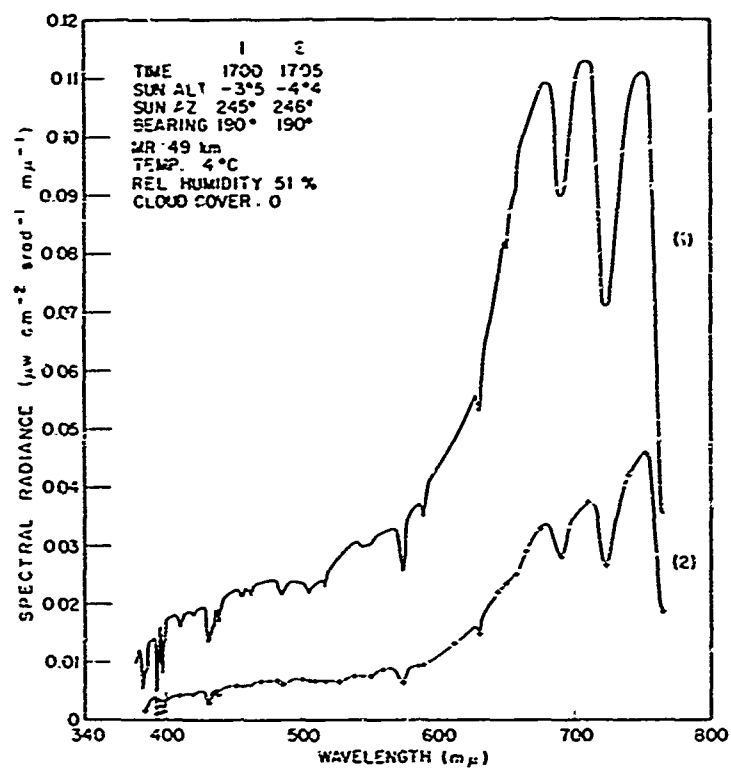Fig. 5a - Spectral radiance of south horizon
over water after sunset

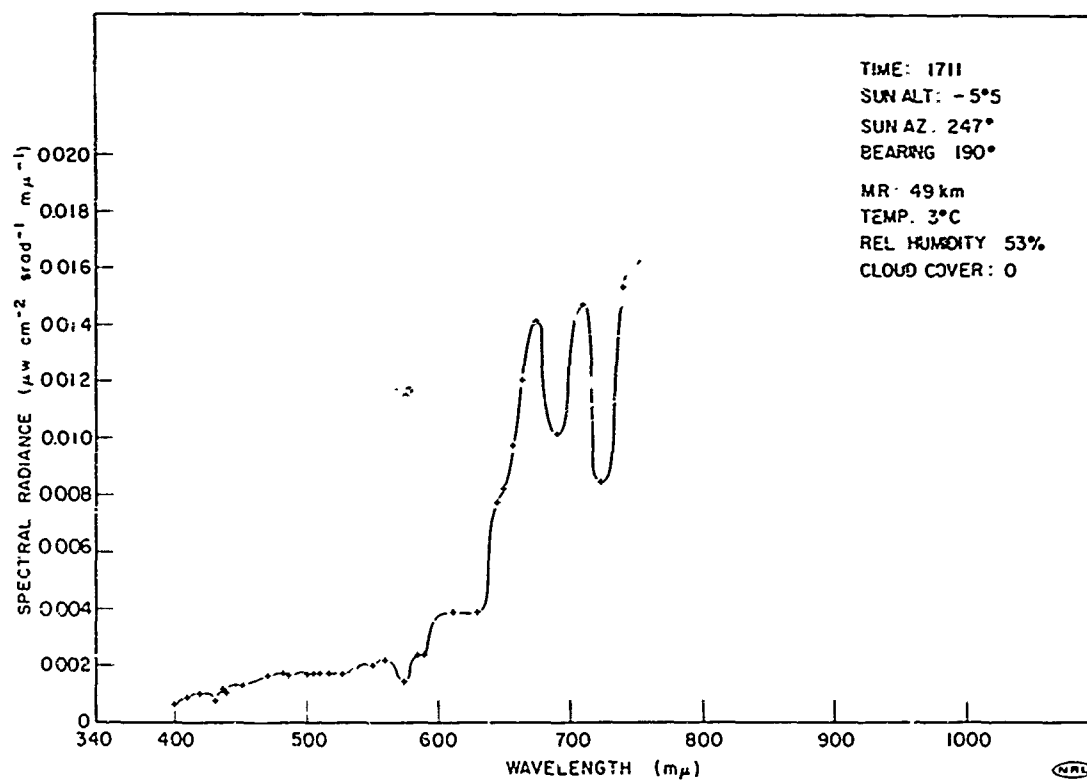Fig. 5b - Spectral radiance of south horizon
over water after sunset

Fig. 5c - Spectral radiance of south horizon
over water after sunset

The curves in Figs. 1b and 1c represent eastward observations at sunrise. Figure 2b presents data for northward and westward observations at or near sunrise. Most of the atmospheric and solar absorption structure is identified in Fig. 2b. Several of the Fraunhofer lines are masked by atmospheric absorption bands; e.g., the sodium-D lines at 589 mμ are masked by the 590-mμ water vapor band. The Fraunhofer C line at 656 mμ, however, is resolved from the water vapor band at 650 mμ. The bands attributed to water vapor are at 505, 545, 590, 650, 730, 823, and 945 mμ, and their strength depends upon the humidity and the length of air path, which in this case depends only on the sun's altitude. The strength of the oxygen bands at 573, 630, 690, and 765 mμ is dependent only upon the air path traversed by the light.

A group of data (Fig. 3) which represented relatively high solar altitudes showed an inverse relationship between radiance and meteorological range which was more pronounced toward the east than toward the north. Little correlation existed between horizon radiance and solar altitude within this group of data. The radiance values shown in Fig. 3e are typical for a clear sky and atmosphere near noon with peak values of 6 μw/cm^2-srad-mμ for the north horizon to 13 μw/cm^2-srad-mμ toward the southeast. Influence of the sun's position is shown in the upper curves of Figs. 3a through 3c, where the low altitude of the sun, combined with the proximity of its azimuth to the observation bearing, produced peak radiances which were approximately three times the radiance values in other directions.

The data in Fig. 3f were obtained when the sky was completely overcast and show decidedly stronger water vapor absorption due to the high humidity and to the increased air path caused by the diffusion of light in the clouds. The oxygen absorption also has been enhanced by the increase in air path. MacAdam (5) noted the same phenomenon to a lesser degree when observing light from the zenith of an overcast sky. The greater amount of blue light in curve 1, compared to that in curve 2, was noted in two other instances (Figs. 2d and 4a) and is believed to be a multiple-scattering effect.

CONCLUSION

The spectral radiance of the horizon sky was found to be a function of the altitude of the sun, the azimuth of the sun relative to the direction of observation, humidity, cloud cover, and meteorological range. Radiance values at noon when the sky was clear and the meteorological range was 30 km or greater were of the order of 10 uw/cm^2-srad-mμ. No difference could be found between land and sea horizons, but a difference would be quite possible if the land horizon were viewed in an industrial area because of the different particle-size distribution.

ACKNOWLEDGMENT

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5.   MacAdam, D.L., J. Opt. Soc. Am. 48:832 (1958)

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13 ABSTRACT

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DD FORM 1473 (PAGE 1)   15

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Spectral radiance						
Horizon sky						
Monochromator						
Sun azimuth						
Meteorological range						
Solar altitude						

DD FORM 1473 (BACK)   16   GPO 934-220

(PAGE 2)